Diaphragm Performance in Steel Frame Structures

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OUTLINE

Objectives

Diaphragm Modeling (Truss method)

WSP Axial Strength

Diaphragm Stability

Conclusions

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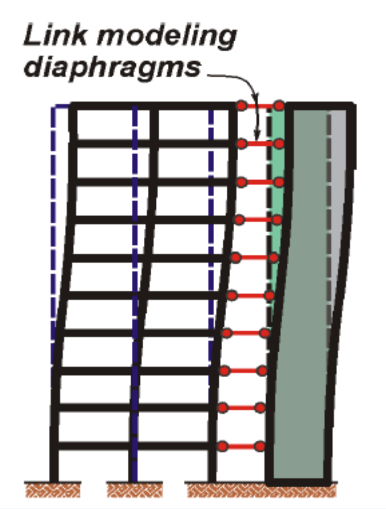
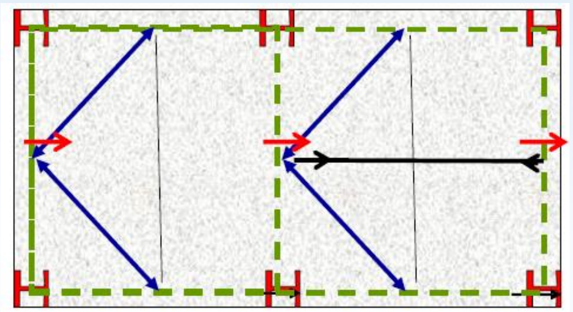


Diaphragm In-Plane Demands

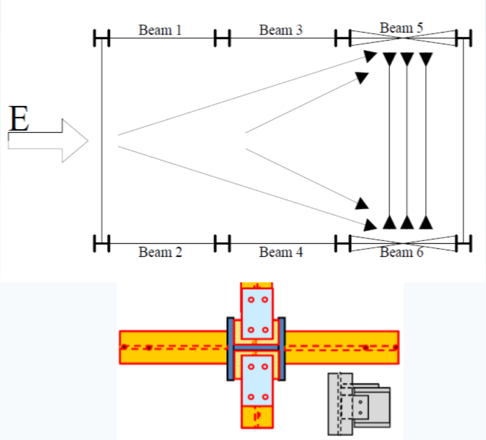
1. *Inertia forces*
2. *Transfer forces*
3. *Slab bearing forces*
4. *Compatibility forces*
5. *Interaction with other elements*

Methods to Find Diaphragm Imposed Forces

1. *Detailed NLTH*
2. *Equivalent Static Analysis (ESA)*
3. *pseudo Equivalent Static Analysis (pESA) [Bull 1997 and Gardiner 2011]*
4. *Parts & Components method (P&C)*



(MacRae and Bull, 2015)



(MacRae and Bull, 2015)

Diaphragm Analysis

1. *Finite Element Method*
2. *Deep Beam*
3. *Strut and Tie*
   - ***Truss method (automated strut-and-tie)***

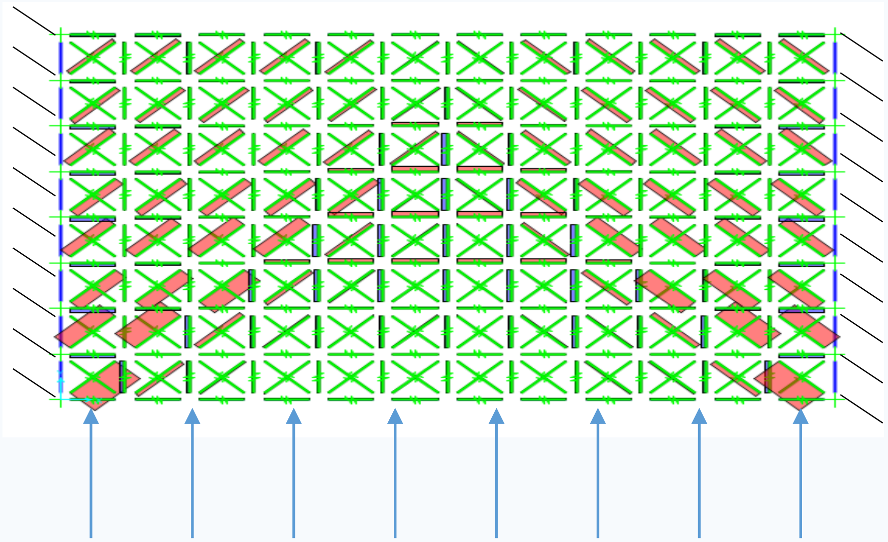
Design & Detailing

1. *Diaphragm strength*
2. *Load path to VLFR system*
3. *Diaphragm stability*

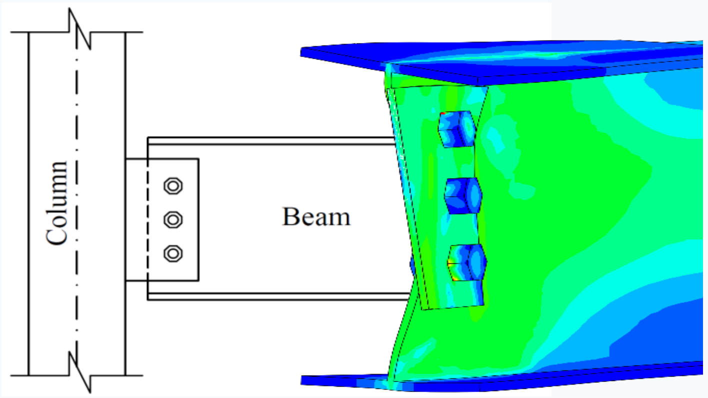
Objectives

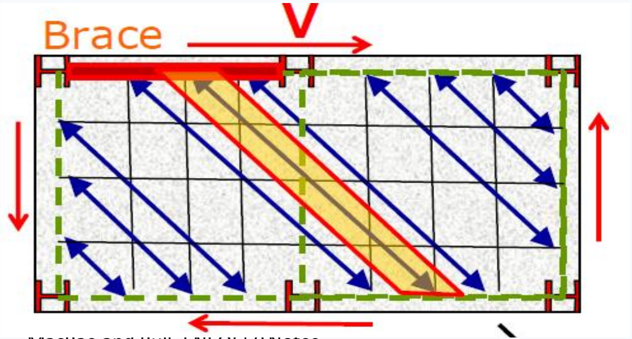
- Develop reasonable method for diaphragm truss element modeling
- Investigate the load transfer mechanism from diaphragm to VLFR system
- Investigate diaphragm stability issue
- Provide recommendations for diaphragm design

Modeling

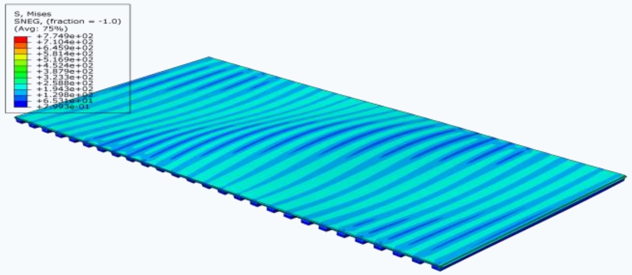


Detailing





MacRae and Bull, ENEQ650 Notes



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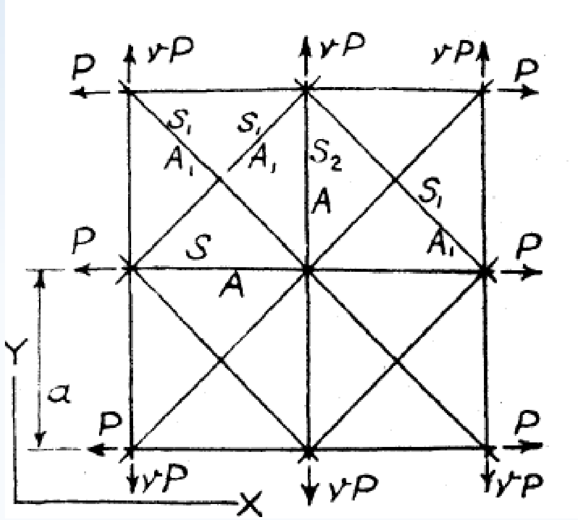
Diaphragm Modeling (Truss method)

Hrennikoff (1941) states that the effective width of the diagonal struts to provide the appropriate stiffness

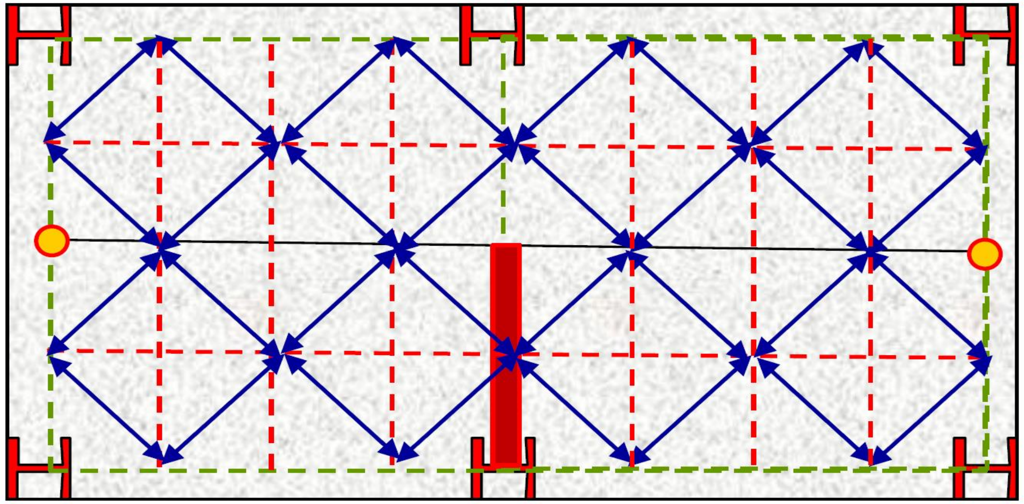
w = 0.53a

Hrennikoff's recommendations are based on many assumptions (e.g. v = 0.33, square blocks, and struts carry both tension and compression)



Diamond shape model

In steel frame structures, studs on the top of any beam can be represented by one effective stud at the center of the beam span (MacRae and Bull, 2015).

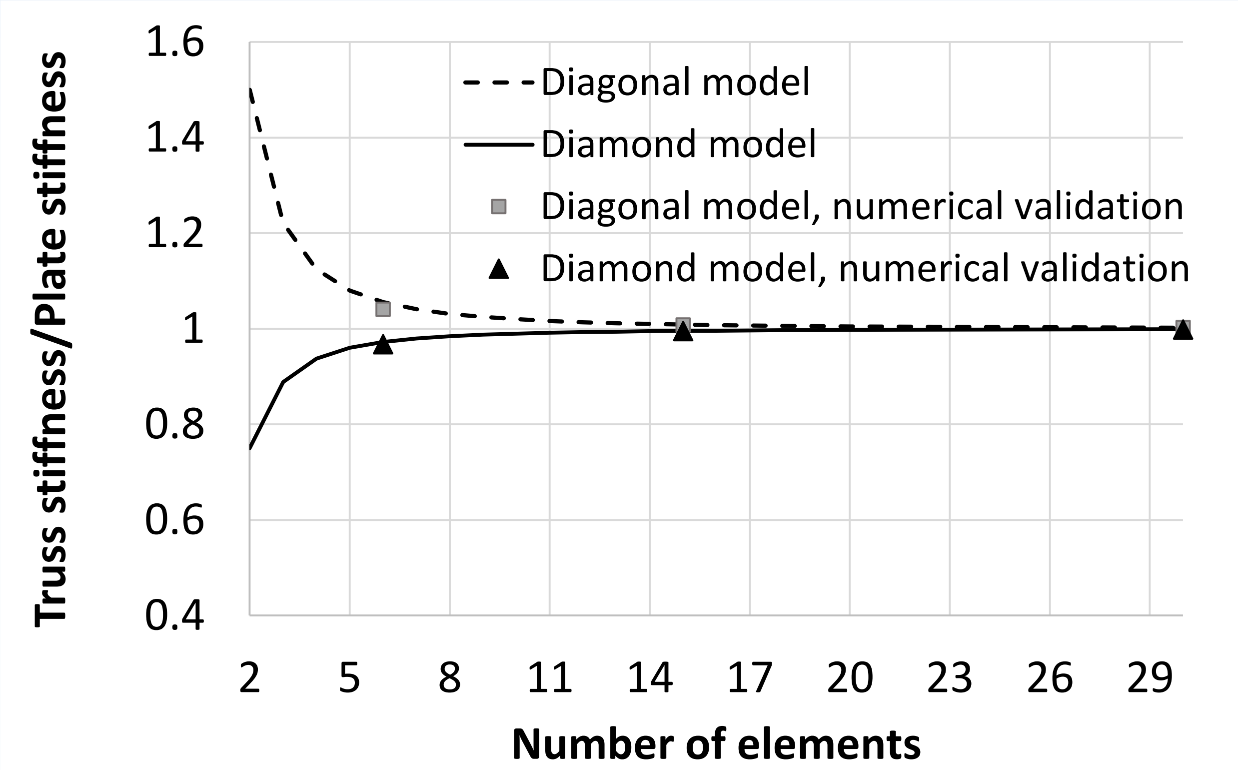


$$A_{\text{Orthogonal}} = 0.75at$$

$$A_{\text{Diagonal}} = 0.53\,at$$

Diaphragm Modeling (Truss method)

Truss Method Stiffness



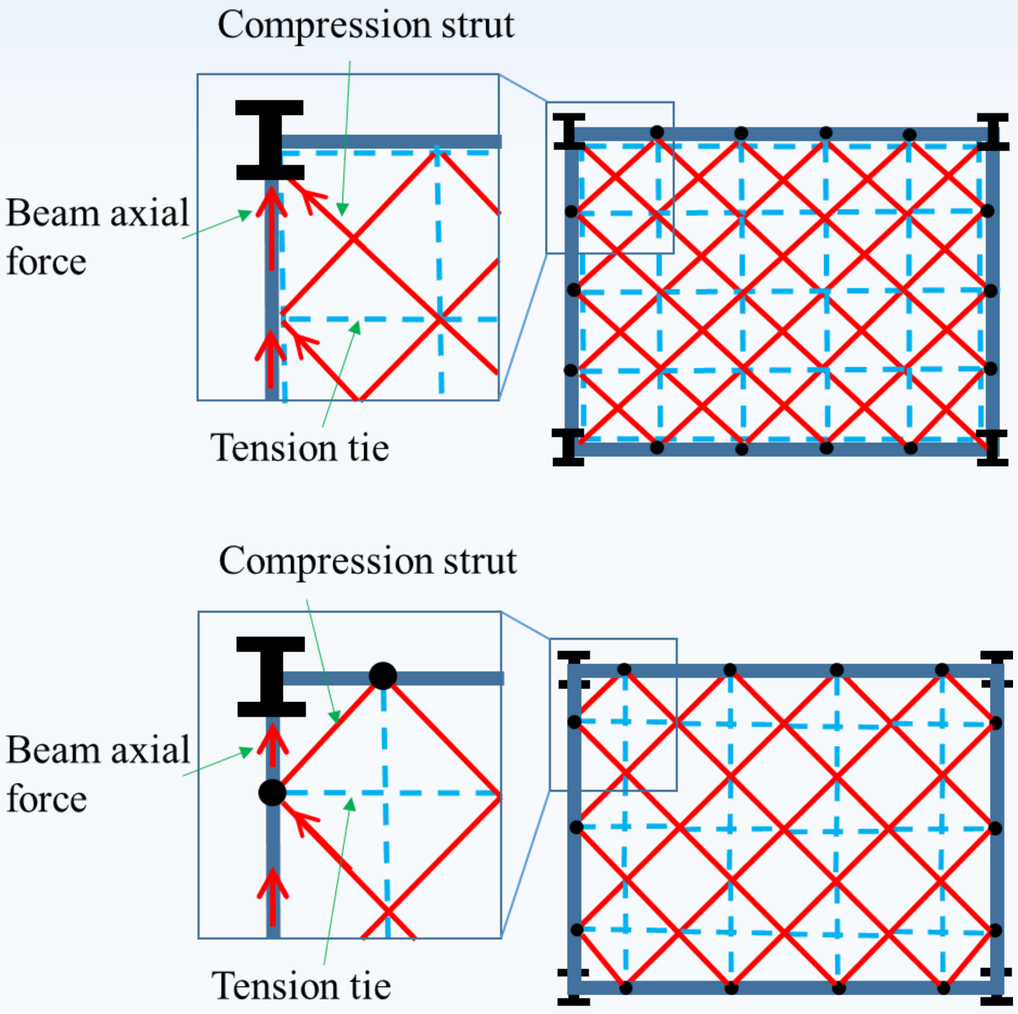
Diagonal model:

3 elements → 22% stiffness error

Diamond model:

3 elements → 11% stiffness error

Beam Axial Force



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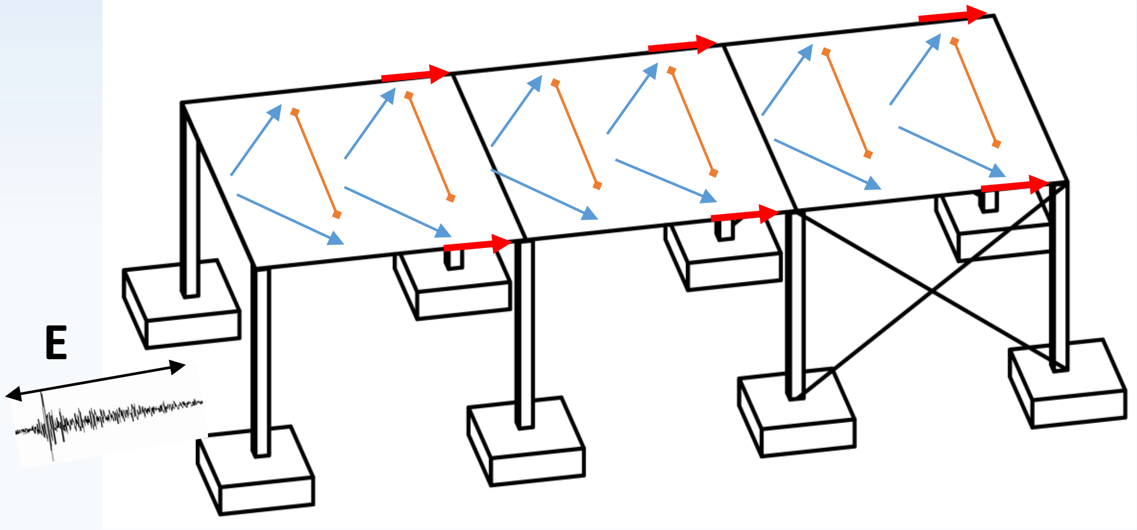
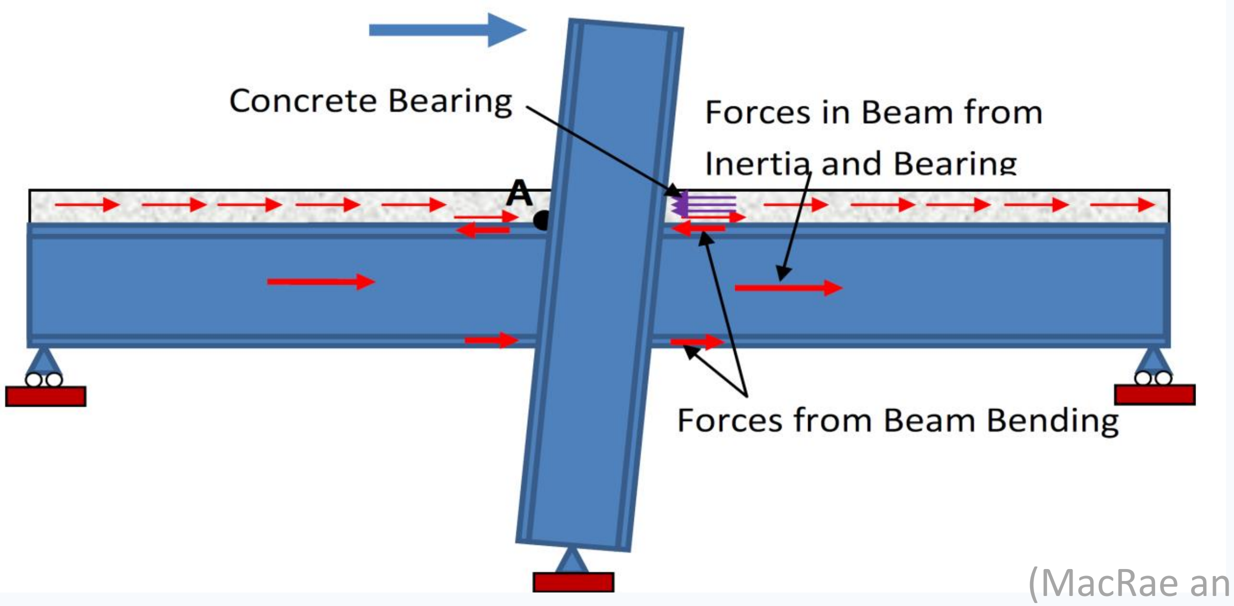
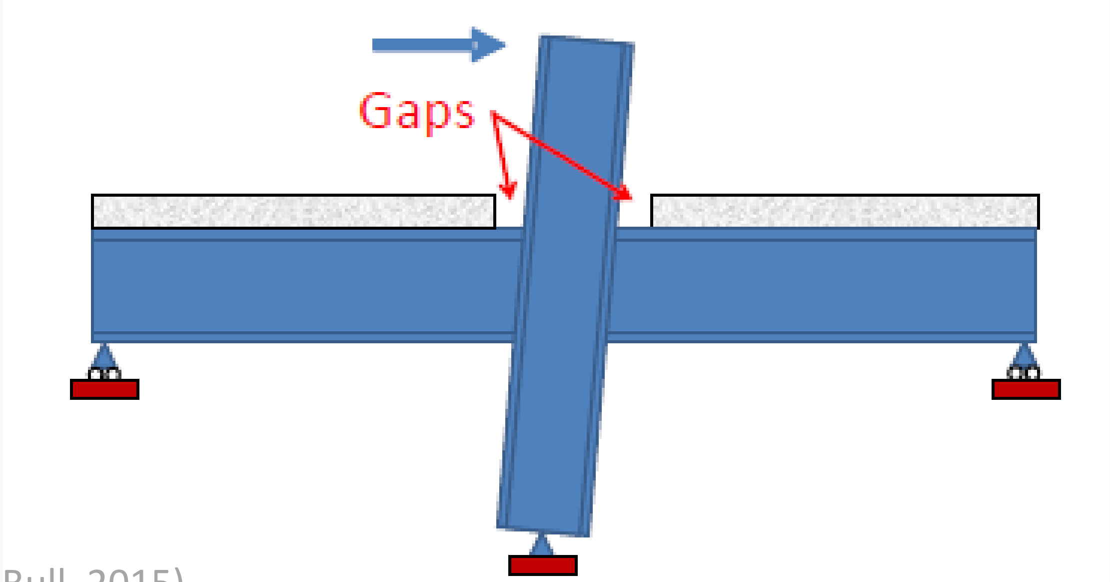
Beam Axial Force Demand:



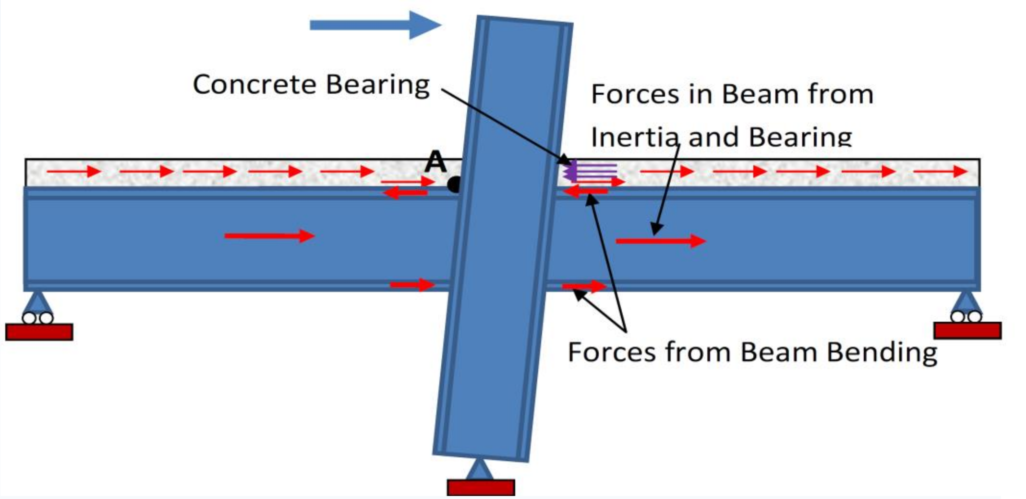


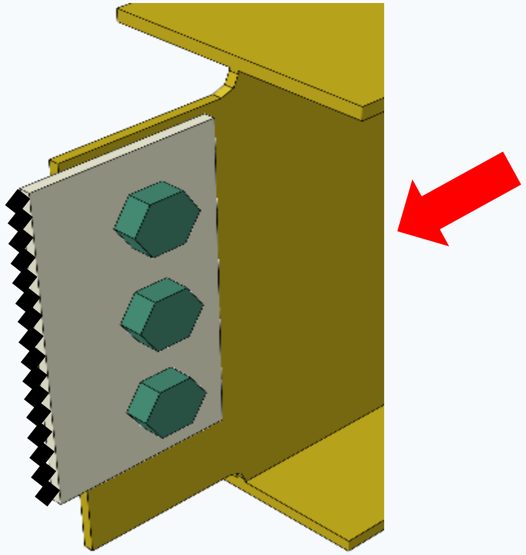


(MacRae and Bull, 2015)

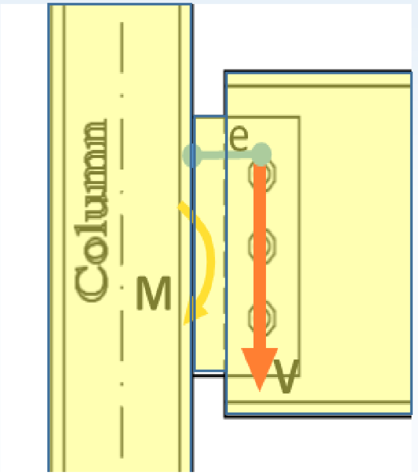
WSP Axial Strength

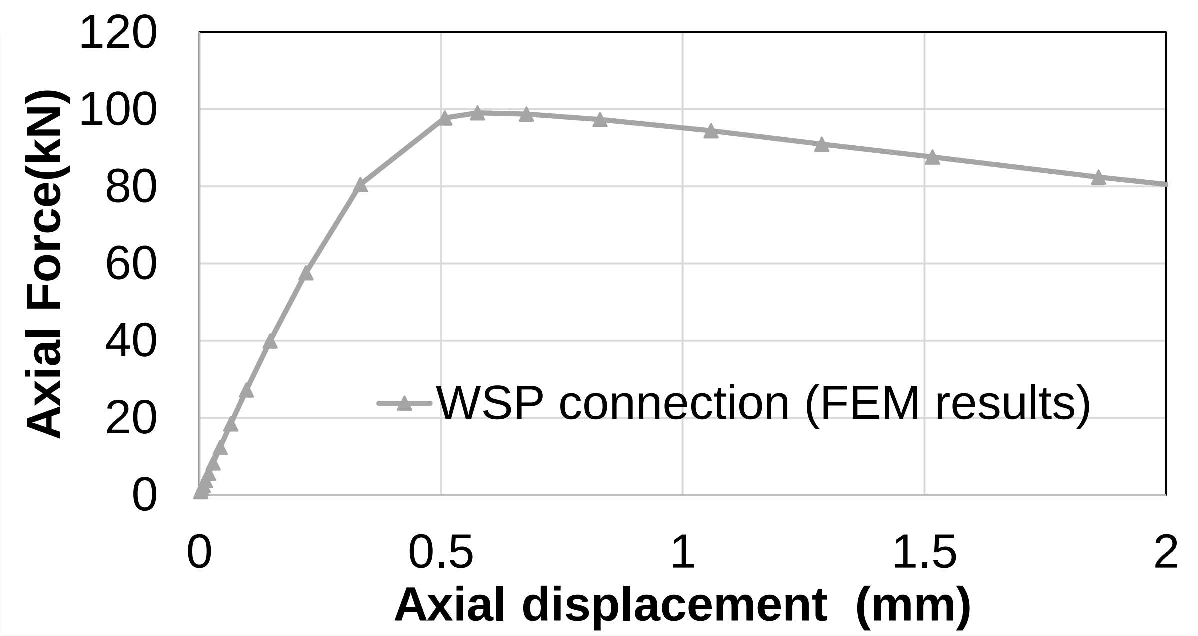
Beam Axial Force Demand





WSP Connection

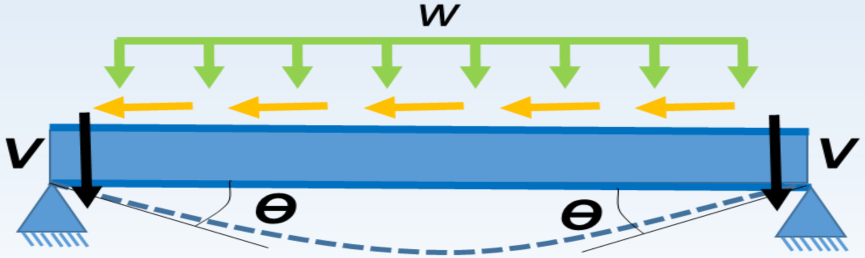




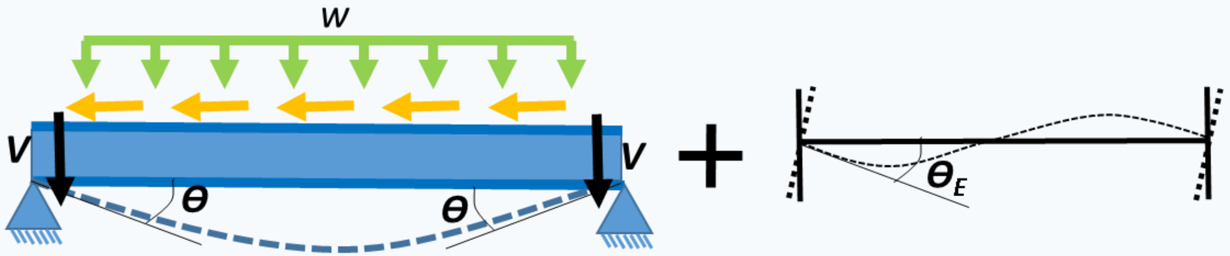
WSP Axial Strength

1 - Gravity forces

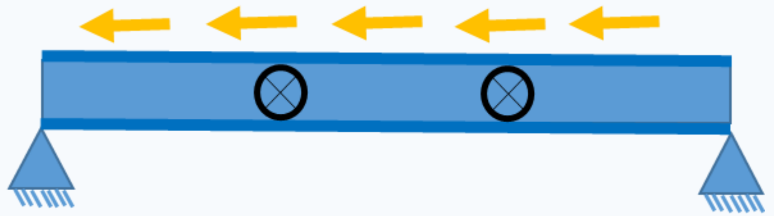
(shear force and beam-end rotation)



2 - Lateral Drift Effect

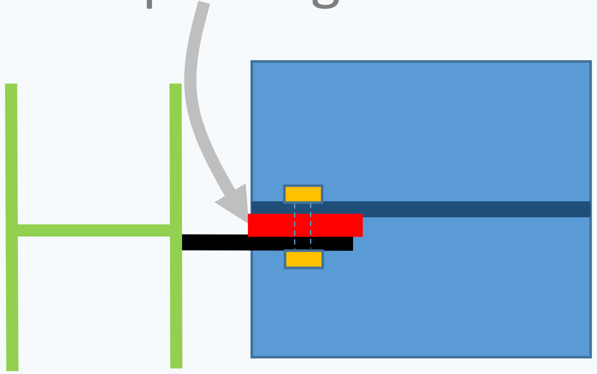


3 - Beam lateral restraint

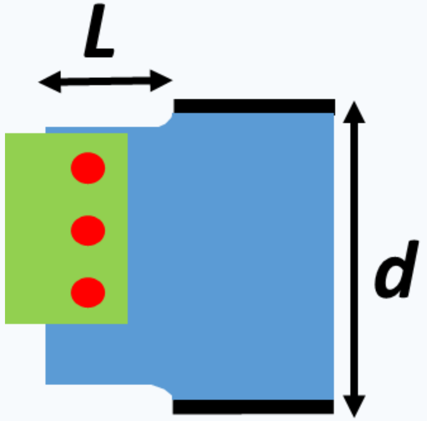


4 - Packing effect (NZS3404)

3mm packing allowed



5 - Cope length



WSP Axial Strength

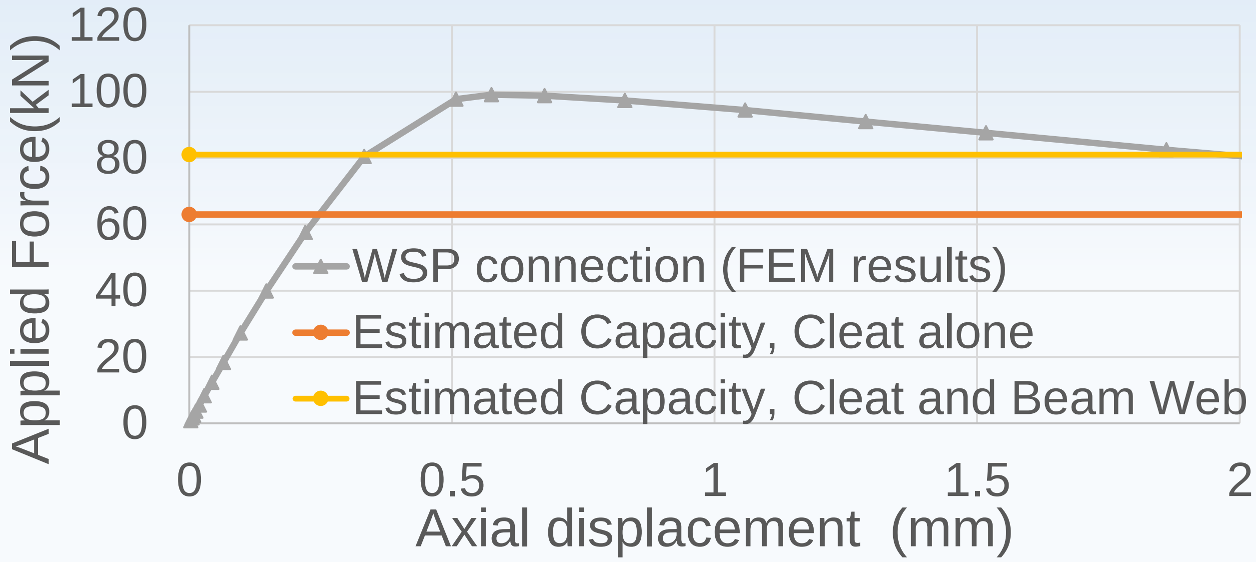
WSP Axial Compression Strength

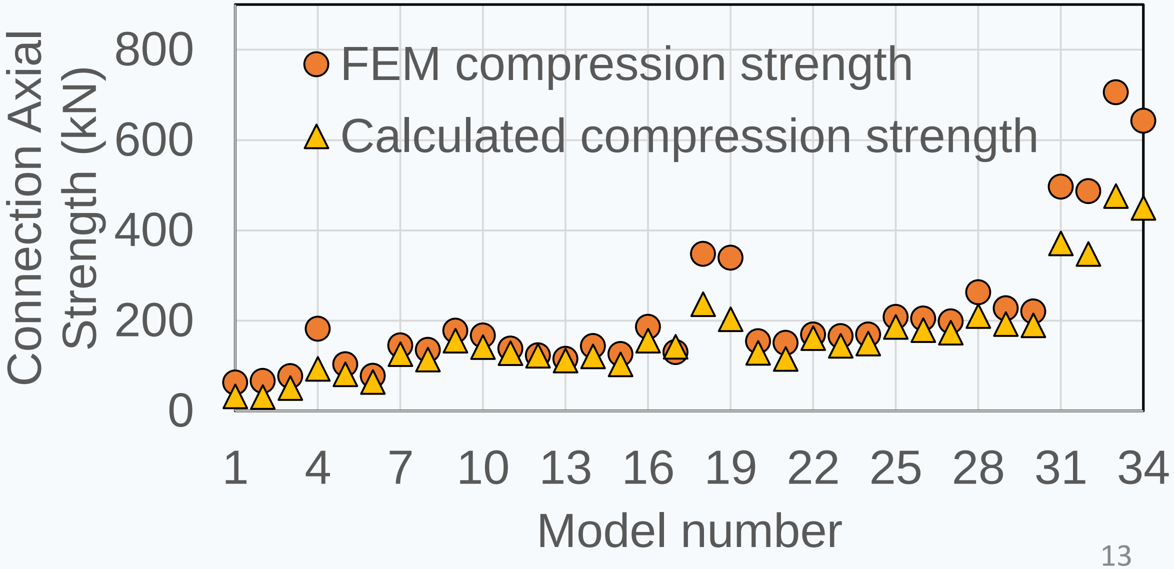
$$\frac{P}{P_u} + \frac{\alpha \times M_0}{M_u(1 - P/P_{cr})} \leq 1$$

$$\alpha = \left(\frac{I_{cleat}/L_{cleat}}{I_{cleat}/L_{cleat} + I_{web}/L_{web}} \right)$$

$$\boldsymbol{k_c} = \frac{\boldsymbol{\pi}}{\boldsymbol{\emptyset_c}} \qquad \emptyset_c \cong \sqrt{\frac{3\frac{L_b}{L_{cleat}}}{\frac{9}{8}\frac{L_b}{L_{cleat}} + 1}}$$

The average ratio of calculated strength to FEM analysis strength is about 80.1% with standard deviation of 13.7%.





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Diaphragm Stability

➢ Minimum floor diaphragm thickness may be governed by

In-service vibration, Fire insulation, Acoustic insulation, and In-plane forces

Buckling modes

1. Inter-Rib

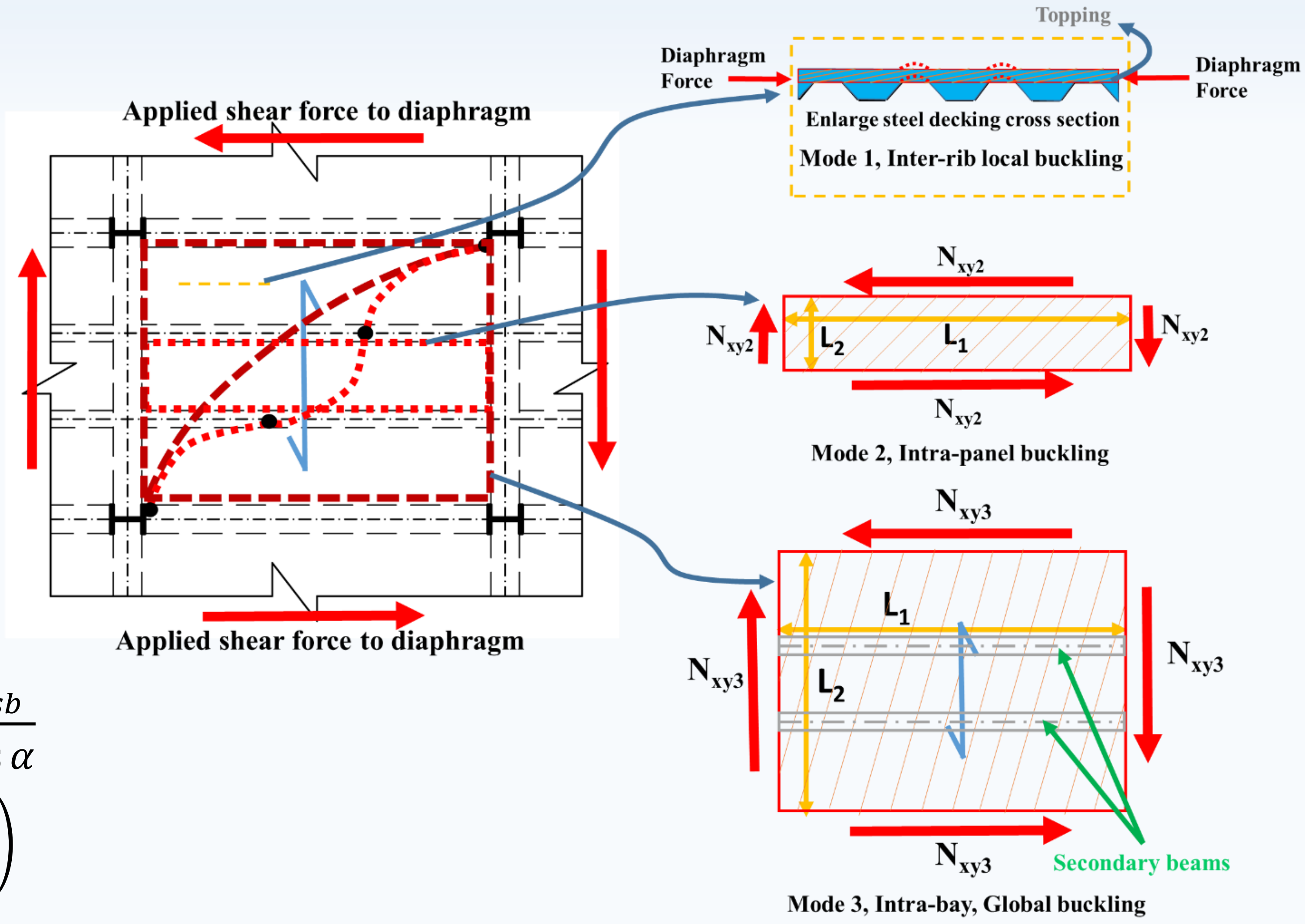
   Inter-rib buckling does not occur for conventional floor slabs.

2. Intra-Panel

$$P_{cr} = \frac{\pi^2\left(EI_s + EI_r\left(\frac{L_s}{L_2}\right)^3\right)}{{L_s}^2}$$

3. Intra-bay

$$P_{cr} = min\begin{cases}\frac{\pi^2 EI_s}{{L_s}^2} + \frac{\pi^2 EI_r}{{L_2}^2 \sin\alpha} + \psi\frac{\pi^2 E_s I_{sb}}{{L_1}^2 \cos\alpha} \\ (n+1)^2\left(\frac{\pi^2 EI_s}{{L_s}^2} + \frac{\pi^2 EI_r}{{L_2}^2 \sin\alpha}\right)\end{cases}$$



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Summary and Conclusion

Truss element modelling

❖ Diamond truss method

i. Provides more reasonable beam axial force compare to the diagonal model

ii. Is less sensitive to the number of truss mesh units

WSP axial strength

❖ Parameters investigated include

i. Gravity loads

ii. Column lateral drift

iii. Cope length

iv. Packing effect

v. Beam lateral restraint along the length

❖ A simple design method to assess axial strength of WSP connection is proposed.

Diaphragm stability

❖ Three diaphragm buckling modes are investigated, include

i. Inter-rib

ii. Intra-panel

iii. Intra-bay

❖ A method is developed to assess diaphragm buckling capacity.

Thank you